Determinants for Live Holding the Spot Prawn *Pandalus Platyceros,* Brandt

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by

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ABSTRACT

Whyte, J.N.C. and B.L. Carswell. 1982. Determinants for live holding the spot prawn, Pandalus platyceros, Brandt. Can. Tech. Rep. Fish. Aquat. Sci. 1129: v + 29 p.

Statistical information on past landings, fishing effort, landed values and catch per unit effort of the shrimp fishery in British Columbia illustrated the need for quality maintenance of the harvested spot prawn, ideally by methods of transportation and holding of live animals. Basic environmental determinants identified for live holding of Pandalus platyceros were salinity levels ranging from 25 to 35°/oo with an optimum at 30°/oo, a minimum holding temperature of 5°C and an oxygen level above 3.5 mg per litre in 30°/oo salinity seawater. Metabolic rates of the prawn at salinities within tolerance levels were similar but were considerably depressed below tolerance levels, reflecting osmoregulatory failure. Metabolism declined significantly in the prawn subjected to conditions of starvation. Increased mortality was proportional to increased holding densities in all size classes, with the first and second year size classes exhibiting a higher mortality at all densities as a function of moulting frequency. Exposure to non-optimum conditions resulted in necrosis of the abdominal tissue and was the major cause of mortality in short-term holding of P. platyceros.

Key words: shrimp fishery, marine crustaceans, prawn, Pandalus platyceros, salinity and temperature tolerances, population density, metabolism.

RÉSUMÉ

Whyte, J.N.C. and B.L. Carswell. 1982. Facteurs déterminants pour le maintien à l'état vivant de la crevette tachetée, Pandalus platyceros, Brandt. Can. Tech. Rep. Fish. Aquat. Sci. 1129: v + 29 p.

Les données statistiques sur les prises, les conditions de pêche, la valeur de la prise et le prix unitaire de la pêche à la crevette dans le passé, en Colombie Britanique, illustrent le besoin de maintenir la qualité de la récolte de la crevette tachetée, idéalement par les méthodes de transport et par le maintien des animaux à l'état vivant. Les facteurs déterminants environnementaux de base reconnus pour le maintien à l'état vivant de Pandalus platyceros sont: un niveau de salinité allant de 25 à 35°/oo avec un optimum de 30°/oo, une température de maintien minimale de 5°C et un niveau d'oxygène supérieur à 3.5 mg par litre dans l'eau de mer de 30°/oo de salinité. Le taux du métabolisme de la crevette dans des salinités endéans des niveaux tolérables était similaire mais il était considérablement diminué à des niveaux plus bas, reflétant une faillite osmorégulatoire. Le métabolisme diminuait de manière significative chez les crevettes affamées. La mortalité augmentait proportionellement à la densité de la population dans toutes les catégories de tailles, avec celle de la première et seconde année montrant une mortalité supérieure à toutes densités en fonction de la fréquence de la mue. L'exposition à des conditions non optimales avait comme résultat la nécrose des tissus abdominaux et était la cause principale de mortalité dans la captivité à court terme de P. platyceros.

Mots clés: pêche à la crevette, crustacé marin, crevette, Pandalus platyceros, tolérance à la salinité et à la température, densité de la population, métabolisme.

INTRODUCTION

Natantian decapod crustaceans, consisting of warm-water Penaeid shrimps and the more ubiquitous cold-water Carid shrimps, are one of the world's most commercially valuable group of marine species. Carid shrimps are harvested commercially in the Pacific off Alaska (Barr 1970) British Columbia (Butler 1968) California (Dahlstrom 1970) and Chile (Hancock and Henriquez 1968).

The Pandalidae family of the Caridea harvested off the coast of British Columbia is represented by the genera Pandalopsis and Pandalus of which nine species are known; Pandalopsis dispar Rathbun (sidestripe or giant red shrimp), Pandalus platyceros Brandt (spot prawn or prawn), P. jordani Rathbun (smooth pink or ocean shrimp), P. borealis Krøyer (pink or northern shrimp), P. hypsinotus Brandt (humpback or king shrimp), P. danae Stimpson (coonstripe or dock shrimp), P. tridens Rathbun (yellow-leg pandalid), P. stenolepis Rathbun (rough patch shrimp) and P. goniurus Stimpson (flexed pandalid). Most abundant of this family are the first six species listed which form the mixed shrimp trawl fishery and the largest member Pandalus platyceros (Fig. 1) which constitutes the prawn trap fishery. Mean dimensions of the prawn up to a 4th year size class illustrates the growth pattern over the life of this animal, Fig. 1, (Butler 1964).

Shrimps were harvested near Victoria before 1890 (Rathbun 1900) and shortly afterwards trawl fishing began in Burrard Inlet. Total shrimp including prawn landings from 1956 to 1975 averaged 706 tonnes/year (Fig. 2) but in the two subsequent years a four to five fold increase in harvest resulted from the discovery and fishing of large populations of P. jordani on the continental shelf off Tofino. From these peak harvest years production declined to a more historic level in 1980 of 656 tonnes (Fig. 2). Increased percentages of prawns in the total shrimp landings from 1976 reflect the significant increase in trap landings as opposed to trawl landings (Fig. 3) such that by 1980 prawns constituted 56% of all shrimps landed. Trawl days fished remained reasonably constant from 1971 to 1980, 2894 SD $\pm$ 335 days/year, while catch per unit effort over this period fluctuated markedly (Fig. 4). Conversely prawn trap days fished from 1975 to 1980 increased from 737 to 8808 days/year while the catch per unit effort declined steadily over this period from 97 to 42 kg/day (Fig. 4). Consequently prawns have become an

increasingly valuable component of the shrimp fishery in British Columbia comprising 78.2% of the $2.7 million shrimp fishery in 1980 (Fig. 5).

Knowledge that harvests from natural stocks of prawns were close to the maximum sustained yield, that mariculture was currently economically unfeasible (Neilson 1981), and that considerable effort was required in trapping this high-priced fisheries commodity, all indicated that every effort should be made to assure quality of this landed resource up to the retail market level. Live holding was considered the optimum condition for quality assurance but although natural stocks of Pandalus platyceros have been studied (Butler 1964 and 1970, Scrivener and Butler 1971) little was known of environmental stresses associated with holding and transporting this crustacean live.

Environmental factors influencing live holding would include salinity-thermal- and ambient oxygen-levels together with concentration of toxic waste metabolites. Behavioural related stresses would be associated with aggression from holding densities of different size classes and with cannabalism from undernourishment during extended holding periods. This report presents some physiological effects of live holding Pandalus platyceros and includes tolerance limits to the major environmental variables and holding densities for specific size classes.

MATERIAL AND METHODS

Specimens were caught by long-line traps at various locations in Howe Sound and transported in natural unfiltered seawater (29 $\pm$ 1°/oo, 10.5 $\pm$ 2°C, at oxygen saturation) to the holding facilities at the West Vancouver Laboratory. Holding tanks were shaded, had a flow-through design providing approximately 30 L/min flow rate of constantly aerated seawater (27 $\pm$ 2°/oo, 10.5 $\pm$ 2°C) maintained at a depth of 1 m. Prawns were fed daily with an excess of the mussel Mytilus edulis.

Salinity tolerances. Solutions ranging from 15 to 40°/oo salinities were established by the addition of distilled water or sea salt to filtered (5 m) seawater, and concentrations verified with a YSI model 33 conductivity meter. Eight prawns (2-3 yr size class, 29.38 mm SD $\pm$ 4.02 mm) held in 12°C and

27.5°/oo seawater were transferred directly into each test solution which was constantly aerated. Observations were made at intervals which increased progressively with the duration of the experiment. Mortalities were tallied after each interval using cessation of scaphognathite beating, cessation of limb activity and no response to tactile stimuli as criteria of death.

Temperature tolerances. Prawns (random 1-4 yr size class) acclimated to 12°C and 28°/oo seawater were transferred directly into 15 L aquaria filled with 0.22 µm filtered seawater at 28°/oo and 0, 3 and 5°C. Animal mortalities were quantified over a 48 hr holding period, then the process was reversed to determine mortalities resulting from thermal shock on direct transferral back to 12°C seawater for a 48 hr period. This procedure was repeated but with gradual acclimation of prawns at 1°C/hr from 12°C to 0, 3 and 5°C and vice versa. Aquaria seawater was not changed during the 48 hr storage period and triplicate trials were performed.

Density/size related mortalities. Perforated plastic trays (bottom area 1120 cm^2, total surface containment area 4914 cm^2, total volume 12,240 cm^3) were filled with prawns of four size classes (1, 2, 3 and 4 yr, Fig. 1) to different densities (1/100 cm^2, 2/100 cm^2, 4/100 cm^2) and stacked in flow-through tanks irrigated with unfiltered seawater at 30 L/min. Translucent fiberglass covers on the tanks reduced the intensity of natural light to 3% of the incident as measured by a light meter. Test animals were not fed during the experiment which was conducted in triplicate. Trays were inspected daily for a period of a month during which mortalities were recorded and removed from the trays; no replacements were made allowing densities to decline naturally.

Metabolic rate relative to starvation. Only prawns acclimated to the holding facilities and fed for at least 1 month were used for metabolic measurements. Prawns of the same size class were transferred to an indoor tank with identical water conditions and starved for 20 hr to allow clearing of the digestive tract. Animals were blotted, including the gill chamber, to remove excess moisture then weighed prior to placing in a static respirometry apparatus, Fig. 6, consisting of a 1 L darkened flask as the respiratory chamber. The chamber was filled with filtered water (25 µm) presaturated with oxygen from the reservoir, and after thermal equilibrium was attained in the constant temperature bath, the prawn was added and water from the reservoir

allowed to flow at 750 mL/min for 2 hr such that total starvation time prior to the assessment of oxygen consumption was exactly 24 hr. A water sample, 300 ml, was taken in a BOD bottle, then water flow discontinued for 30 min after which a further water sample was taken. Samples were fixed by the addition of manganous sulphate and alkaline iodide solution and dissolved oxygen assessed by the method of Winkler (Strickland and Parsons 1968). Metabolic rate of the prawn was calculated from the difference in the oxygen levels in the two samples.

This procedure was repeated at 24 hr intervals ensuring only minimal disturbance to the test animal which was checked once daily after metabolic rate assessment. The first series of animals tested were five third year males with an average weight of 21.48 $\pm$ 0.43 g and the second series of test animals were fourth year females averaging 34.96 $\pm$ 2.40 g.

Metabolic rate relative to ambient oxygen. Animals conditioned as described previously were starved for 2 days then transferred directly to the respirometry apparatus consisting of a darkened steam generator flask, used in a Kjeldahl apparatus, fitted with a dissolved oxygen electrode probe coupled to a YSI model 53 meter and a Fisher Recordall Omniscribe chart recorder (Fig. 7). The chamber was filled with pre-acclimated filtered water (0.22 µm) and equilibrated in the constant temperature water bath. The test prawn was positioned in the chamber, irrigated at 750 mL/min for 30 min then the chamber was sealed and the oxygen level monitored continuously to asphyxial levels.

Metabolic rate relative to temperature and salinity. Specimens preconditioned as described previously were starved for 48 hr and acclimated to experimental temperature and salinity conditions for a period of 6 hr. Acclimation periods were short so that initial effects on metabolic rates might be assessed. Fourth year size class prawns were used in each salinity and temperature combination and oxygen consumption measured in the respiratory chamber, Fig. 6, after a 1 hr depletion interval. Oxygen saturated, 0.22 µm filtered, seawater adjusted to 20, 25 and 30°/oo was used at 5, 10 and 15°C.

RESULTS AND DISCUSSION

Salinity tolerance data of adult prawns, Fig. 8, indicated 100% mortality within 6 hours of immersion in seawater of 15 to 18°/oo salinity. Progressive decrease in mortalities accompanied increased salinity from 20 to 27.5°/oo until at the 30 to 35°/oo concentration no mortalities were evident within 72 hours. At 40°/oo salinity 87.5% mortality occurred within 12 hours indicating the upper tolerance limit was between 35 and 40°/oo. The lower salinity tolerance level, defined as the salinity concentration resulting in 50% mortality over the 72 hour test period, was interpreted from these data to be 21.3°/oo for adult prawns.

The post-larvae of P. platyceros remain in shallow water from the sublittoral zone to 55 m depth until the end of their first year when they migrate to rocky bottom areas of 70-90 m depth (Butler 1970). Normally exposed to dilute seawater as juveniles, these present results suggest, the prawn does not exhibit this tolerance to low salinity when adult. Corroborating these results, salinity and temperature ranges associated with the adult prawn in the Strait of Georgia were reported as 26.43 to 30.83°/oo and 7.61-10.97°C respectively (Butler 1964). In addition, preliminary data from the culture of the spot prawn, indicated maximum growth occurred in seawater at 30°/oo (Wickins 1972).

Mortalities from extremes of salinity were associated with white patches on the abdominal musculature, that portion of the animal which generally constituted 34% of its total weight. These patches would increase gradually converting the entire musculature into opaque, dead tissue by the process described as spontaneous necrosis (Rigdon and Baxter 1970). Causitive factors for this apparent denaturation of the protein musculature are as yet unknown, however, our observations indicated that extensive necrosis in P. platyceros was irreversible particularly when the last segment of the tail was affected and that animals died within 1 to 7 days of showing symptoms.

Some specimens in dilute media exhibited gross lateral distension of the carapace caused by an increase in the fluid levels between the carapace and underlying epithelial layer; considered resulting from osmoregulatory failure. All decapods investigated exhibit ion concentrations in blood plasma different from that of the surrounding medium and different from that which would be expected from a Donan equilibrium (Waterman 1960). When marine crustaceans

are placed in diluted seawater, there is a general loss of ions across the body surface and in the urine with a consequent increase in cellular fluid by osmosis. Failure to maintain an ionic steady state by osmoregulatory processes would result in excessive water accumulation in the body and consequent death of the animal.

Low salinity seawater is a seasonal occurrence in many coastal inlets in British Columbia as illustrated, Fig. 9, by the data from Montagu Channel Oceanographic site in Howe Sound (Levings 1980). In the summer months salinities at the 0 and 5 m depths are within lethal or extremely stressful limits for the prawn and only at the 25 m depth is seawater of adequate salinity for live holding and transportation of prawns.

These data would suggest that seawater for live holding and transportation of P. platyceros should be ideally 30°/oo salinity, but could range from 25 to 35°/oo with increased deviation from these limits resulting in significant mortalities. Suitable water may be obtained from an appropriate depth or adjusting low salinities water with sea salt.

Although the upper lethal temperature for P. platyceros has been reported as 22.9°C (Kelly et al. 1977) no information is available in the literature on the lower tolerance limit. Gradual temperature changes from 12°C to 0, 3 and 5°C for prawns contained in seawater at 28°/oo resulted in complete survival over a 48 hour period, Table 1. On gradual reacclimation to 12°C mortalities occurred among prawns held at 0 and 3°C, with the majority of these animals exhibiting lack of coordination prior to termination. No mortalities occurred in the prawns gradually reacclimated from 5°C. Direct transfer of prawns from 12°C to 0°C resulted in 60% mortality but when transferred directly to 3 and 5°C seawater at 28°/oo no mortalities occurred, Table 2. Direct transfer of these survivors back to initial environmental conditions (12°C, 28°/oo) resulted in 20% mortalities for prawns held at 0 and 3°C, however no mortalities occurred from 5°C. Severe escape response was noted on transfer of the prawns from 0°C followed by an inactive state.

Cold damage to tissue resulted from holding prawns at 0 and 3°C in both the direct and gradual transfer procedures, was evidenced by muscular necrosis, resulting probably from decreased metabolic activity and insufficient energy for osmoregulation.

Organisms with low temperature tolerance limits down to 0°C often suffer more damage from rapid declines in temperature than from the low temperature

experienced (Kinne 1963). Results of direct and gradual transferral of prawns to 0 and 3°C would concur with this observation as much higher mortalities resulted from instantaneous transfer than gradual acclimation to these low temperatures. However, once subjected to cold damage the mode of reacclimation to ambient temperatures would be of minor importance as suggested by the higher percentage mortality in the gradual rather than the direct transfer of prawns from 0 and 3°C to 12°C.

From these data the lower lethal limit for P. platyceros was approximately 3°C and qualitative observations indicated third and fourth year size class animals appeared more susceptible to cold damage. Death resulting from cold damage and subsequent reacclimation to ambient temperatures has also been reported for Cancer magister held at 3.3°C for 5 days (Roach 1956).

Mortality in populations of the cultured prawn Palaemon serratus related directly to the number of prawns per unit bottom area of tank (Forster 1970, Wickins 1972). Effect of population density on size class mortality of P. platyceros indicated increased mortality with increased density in all size classes, Table 3. First year size class at densities of 2 and 4 per 100 cm^2 exhibited significantly greater mortalities than other size classes. In general a trend to increased mortalities was apparent in the smaller size classes. Percentage of mortalities which occurred during moulting for all densities of each size class indicated mortalities during moulting were more frequent in the smaller size classes, Table 3. As the prawns were not fed, to simulate least desirable holding conditions, the extensive cannibalization of newly or semi-moulted prawns in all size classes but particularly the younger animals corresponded to this disparity in percentage mortalities. As intermoult period lengthens with increasing age in crustacea (Lockwood 1968) mature prawns would be less vulnerable to cannibalism. Mortalities due to other factors, such as spontaneous necrosis of muscle and fungal infection in the branchial region, Fig. 1, from Fusarium species, were more prevalent in the larger size classes. To minimize contamination, hygiene control in recirculating holding tanks would be maintained by filtration to the bacterial level using a system proved effective in depuration of oysters from faecal contamination (Whyte and Carswell unpublished data). Less than 10% mortalities for all size classes and densities were recorded over a seven day holding period (Appendix 1).

Oxygen consumption of animals held live is of considerable importance as

it provides an estimate of energy requirements of the animals subjected to various environmental conditions. Variables which can modify oxygen consumption include the nutritional state of the animal, ambient oxygen concentration, temperature, osmotic equilibrium reflecting salinity, stage of moulting cycle, surface area, weight and activity level. As the only activity of the prawns was spontaneous when tested in the static respiratory chambers Figs. 6 and 7, the measurements of oxygen consumption provided "routine metabolic rates" (Fry 1957) of this animal which had not been investigated previously.

Oxygen consumption of third year male and fourth year female prawns was considerably higher in the first day after starvation 0.088 and 0.090 mL oxygen/gram/hour respectively than in subsequent days starved, Fig. 10. The respiratory rate declined by the second day and further starvation caused only slight fluctuations about an average 0.041 and 0.052 mL oxygen/gram/hour; this was a reduction of 53 and 42% in the metabolism of male and female prawns respectively over the extended starvation period relative to the first day. The acute decline in oxygen consumption reflected the effect of starvation (Kutty 1972) rather than any decline in spontaneous activity which is accompanied normally by a more gradual decrease in metabolism (Beamish 1964). This rate of oxygen consumption could be defined as the "starvation rate" since it was determined on animals subjected to starvation. Over an extended fishing or transportation trip this decreased starvation rate would assist effectiveness of live holding systems.

Metabolic rates of prawns, under various temperature and salinity regimes, when plotted against ambient oxygen levels from data fitted statistically with fourth degree polynomials, provided curves with well defined critical concentrations, Figs. 11-13. At 10°C in 30°/oo salinity seawater the metabolic rate was independent of oxygen tension to 3.5 mg oxygen/litre which was 53% of oxygen saturation concentration under these conditions. Below this value the metabolic rate decreased acutely and at ambient concentrations below 0.5 mg oxygen per litre the animals ceased to respire, Fig. 11. Similar critical oxygen concentration and minimal respirable concentrations were exhibited by prawns held at 5°C and 30°/oo, however, the average metabolic rate above critical concentration was halved at the lower temperature, Fig. 12.

An increase in the critical concentration to about 5 mg oxygen per litre

was observed by prawns in seawater at 20°/oo salinity and 5°C and a minimal respirable oxygen concentration was considerably elevated to 2.25 mg oxygen per litre, Fig. 13. It should be noted that 20°/oo was below the lethal limit of the prawn and these data may represent modification to osmoregulatory as well as respiratory functions. Wide variations in metabolic data between specimens and within the same specimen was considered to reflect different levels of spontaneous activity between specimens (Kutty 1972) and variations in the individual animal with time.

Changes in mean metabolic rates of the prawn with temperature and salinity, Fig. 14, indicated a marked increase in rates with increased temperatures when held in 25 and 30°/oo salinity seawater. At 20°/oo the prawns exhibited uniformly low metabolic rates at all temperatures. Statistical analysis of data (see Appendices 2 and 3) confirmed these observations and indicated that at 5 and 10°C there was no difference in rates between specimens held at 25 and 30°/oo, however at 15°C rates were higher in 30°/oo than in 25°/oo salinity water.

Pandalids are known stenohaline organisms, that is, capable of living only in a certain narrow range of salinity. The North Sea prawn P. montagui is nearly isotonic in seawater, being just slightly hypotonic to external media (Panikkar 1968). This species is also a poor osmotic regulator in reduced salinities exhibiting an isosmotic curve over the range 20 to 35°/oo salinity. Similarly with P. platyceros, practically uniform low metabolic rates in 20°/oo, coupled with the salinity tolerance data, suggested failure of osmoregulatory control at this salinity. The response was typical of stenohaline species which suffer osmotic damage when salinities vary significantly from normal levels (Kinne 1964).

Similar metabolic rates for prawns in 25 and 30°/oo salinities at both 5 and 10°C suggested minor differences in the animals osmoregulatory control between these salinities although tolerance data favoured the higher level. High metabolic rates for prawns at 30°/oo and 15°C indicated increased stimulus under these conditions. Water capacity requirements for holding prawns was estimated from these reported data, Table 4. The number of hours required for 100 prawns of 50 g each to half the oxygen level in 100 litres of saturated seawater clearly favoured low temperature storage, Table 4(a). These values related to still water and only approximated values expected from a recirculating, efficiently mixed, holding tank with atmospheric or

compressed air diffusion into the water. An estimate of the volume of saturated water required to replace oxygen uptake, Table 4(b), illustrated the marked difference in the requirements for oxygen saturated water depending on holding temperature.

In summary, the lower limit of salinity for the spot prawn was approximately 21.3°/oo and the salinity range for live holding was 25 to 35°/oo with an optimum value of 30°/oo. Mortalities resulted from holding temperatures of 3°C and less, therefore a lower limit of 5°C was considered ideal for live holding. Under severe holding conditions, increased mortality resulted from increased density in all size classes. In general, the first and second year classes demonstrated higher mortality at all densities which was considered a function of moulting frequency. Under conditions of starvation, oxygen consumption decreased with holding time and this rapid and substantial decline in metabolism was considered advantageous to live transportation. Oxygen consumption of P. platyceros was independent of oxygen concentration to levels of 3.5 to 4.0 mg oxygen per litre in 30°/oo salinity seawater. Below this critical ambient oxygen level, metabolism declined directly with oxygen concentration until asphyxial levels were reached. Prawns in salinities within tolerance levels exhibited similar metabolic rates at various temperatures but when held below the tolerance limit, rates were depressed suggesting osmoregulatory failure. Exposure to temperature and salinity levels beyond tolerance limits, low oxygen levels or physical damage resulted generally in necrosis of muscle tissue in the prawn. This pathology which made the flesh soft and unpalatable accounted for the majority of mortalities as specimens exhibiting this disorder always succumbed, though the length of time was variable. Careful examination of the harvested specimens for necrosis would therefore be advisable if prawns were to be stored live rather than being processed or consumed directly.

Addendum to this report; the determinants identified herein have been applied in the design of a prototype self-contained live holding system suitable for onboard vessel trials. These trials will assess the practicalities of developing live-holding systems to maintain shellfish quality and thereby to improve economic returns to this fishery.

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TABLE 1. Temperature conditions affecting mortality of P. platyceros (gradual temperature changes, 1°C/hr)

Initial temperature °C	Final temperature °C	% Mortalities 24 hours	48 hours
12	0	0%	0%
12	3	0%	0%
12	5	0%	0%
0	12	30%	43%
3	12	43%	43%
5	12	0%	0%

TABLE 2. Temperature conditions affecting mortality of *P. platyceros* (instantaneous temperature changes)

Initial temperature °C	Final temperature °C	% Mortalities 24 hours	48 hours
12	0	60%	60%
12	3	0%	0%
12	5	0%	0%
0	12	20%	20%
3	12	20%	20%
5	12	0%	0%

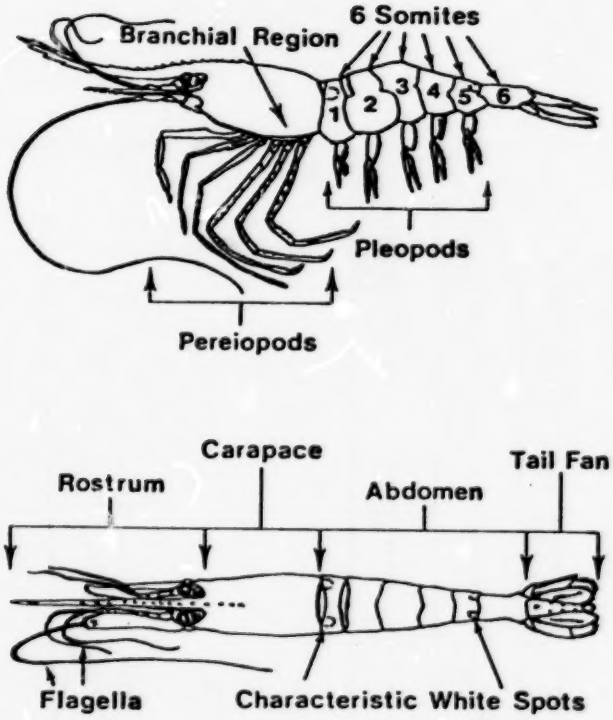
TABLE 3. Effect of population density on size class mortality of *P. platyceros*

Density	Mean percentage mortality after 30 days			
Individuals per 100 cm^2	4 year class (33.7+ mm)	3 year class (33.7-28.5 mm)	2 year class (28.5-21.2 mm)	1 year class (21.2-10.0 mm)
1	6.1% (3)	3.0% (3)	21.2% (3)	21.2% (3)
2	4.5% (3)	9.1% (3)	22.7% (3)	54.5% (3)
4	27.7% (2)	28.9% (3)	26.7% (3)	49.6% (3)
Mortalities during moult	8.0%	48.0%	91.0%	98.0%

Size class based on carapace length (mm).
Number of replicates in parentheses.

TABLE 4. Effect of water temperature on the rate of depletion of oxygen for 100 prawns (*P. platyceros*; 50 g average weight) in 100 litres of seawater (salinity 30°/oo)

	Temperature		
	5°C	10°C	15°C
(a) Time (hours) required to reduce oxygen-saturated seawater to 50 percent saturation	2.99	1.15	0.61
(b) Number of litres/hour of oxygen-saturated seawater required to replace the uptake of oxygen	16.71	43.66	81.49



PARAMETERS	SIZE CLASS			
AGE	1ST YEAR	2ND YEAR	3RD YEAR	4TH YEAR
SEX	MALE	MALE	MALE/FEMALE	FEMALE
CARAPACE LENGTH	TO 21.2 MM	21.2-28.5 MM	28.5-33.7 MM	33.7-42.1 MM
TOTAL LENGTH	TO 107 MM	107-144 MM	144-170 MM	170-200 MM
TOTAL WEIGHT	TO 6.4 G	6.4-15.4 G	15.4-25.1 G	25.1-48.3 G

Fig. 1. The spot prawn, Pandalus platyceros, with mean high and low parameters of size classes, (Butler 1964).

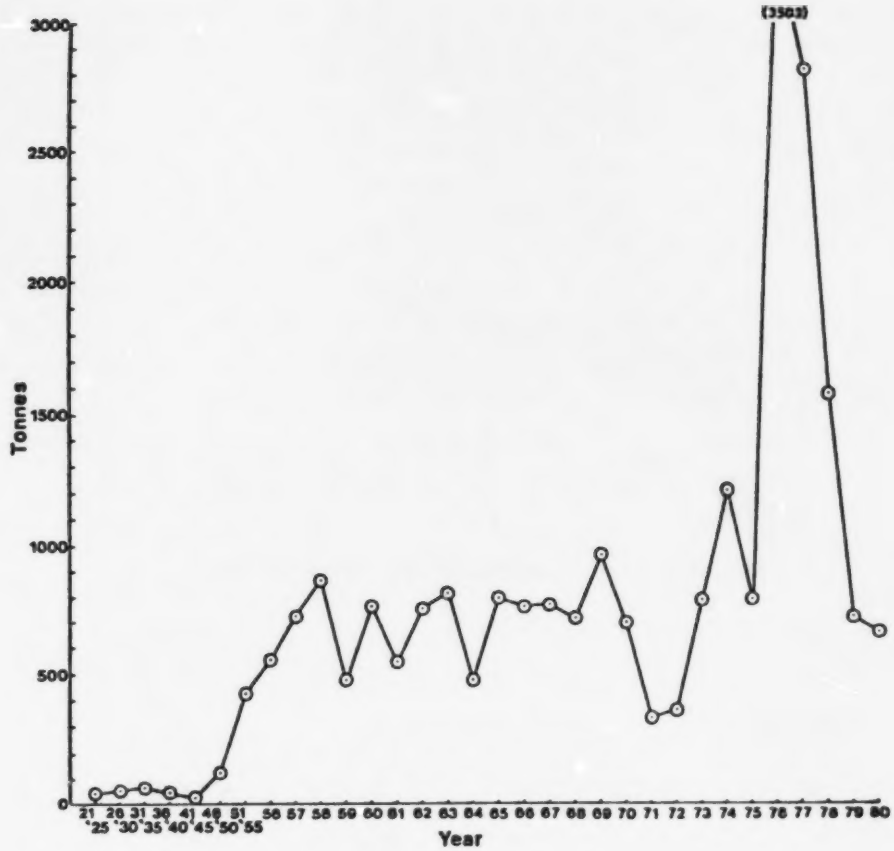


Fig. 2. Total mixed shrimp and prawn landings, 1921-1980 (Annual summary of B.C. catch statistics, Fisheries and Oceans Canada, Pacific Region).

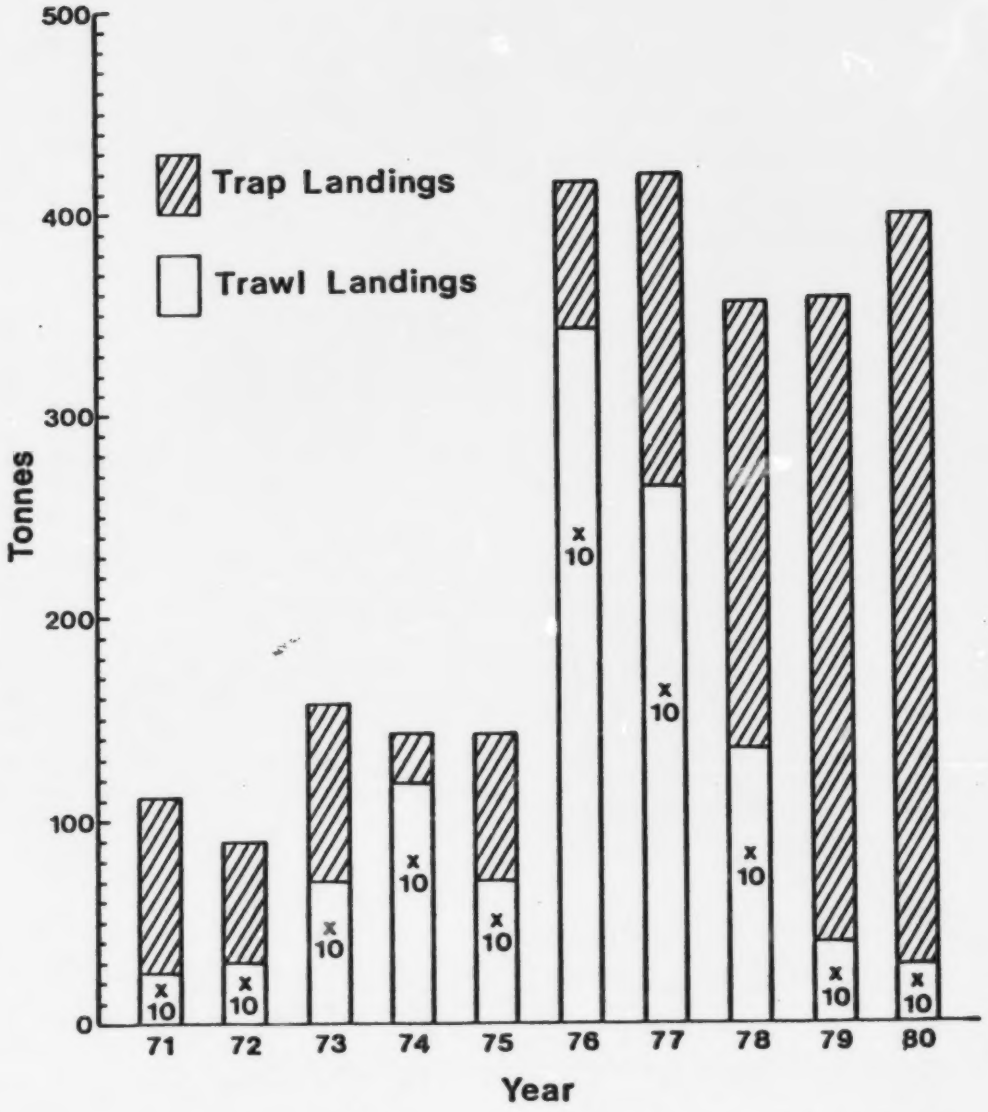


Fig. 3. Trawl and trap landed mixed shrimp and prawns, 1971-1980 (Annual summary of B.C. catch statistics, Fisheries and Oceans Canada, Pacific Region).

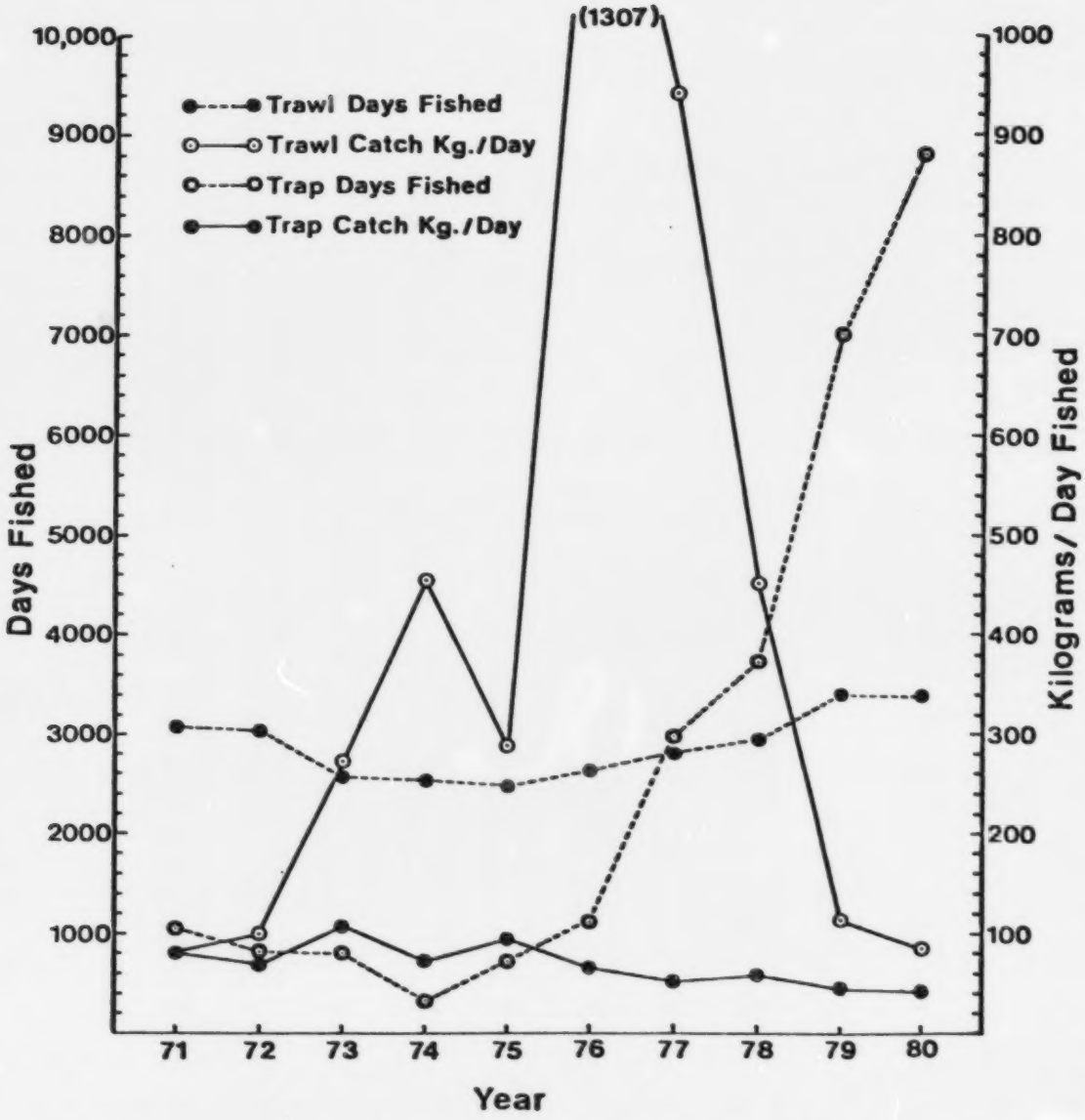


Fig. 4. Mixed shrimp and prawn fishing effort and catch per unit effort, 1971-1980 (Annual summary of B.C. catch statistics, Fisheries and Oceans Canada, Pacific Region).

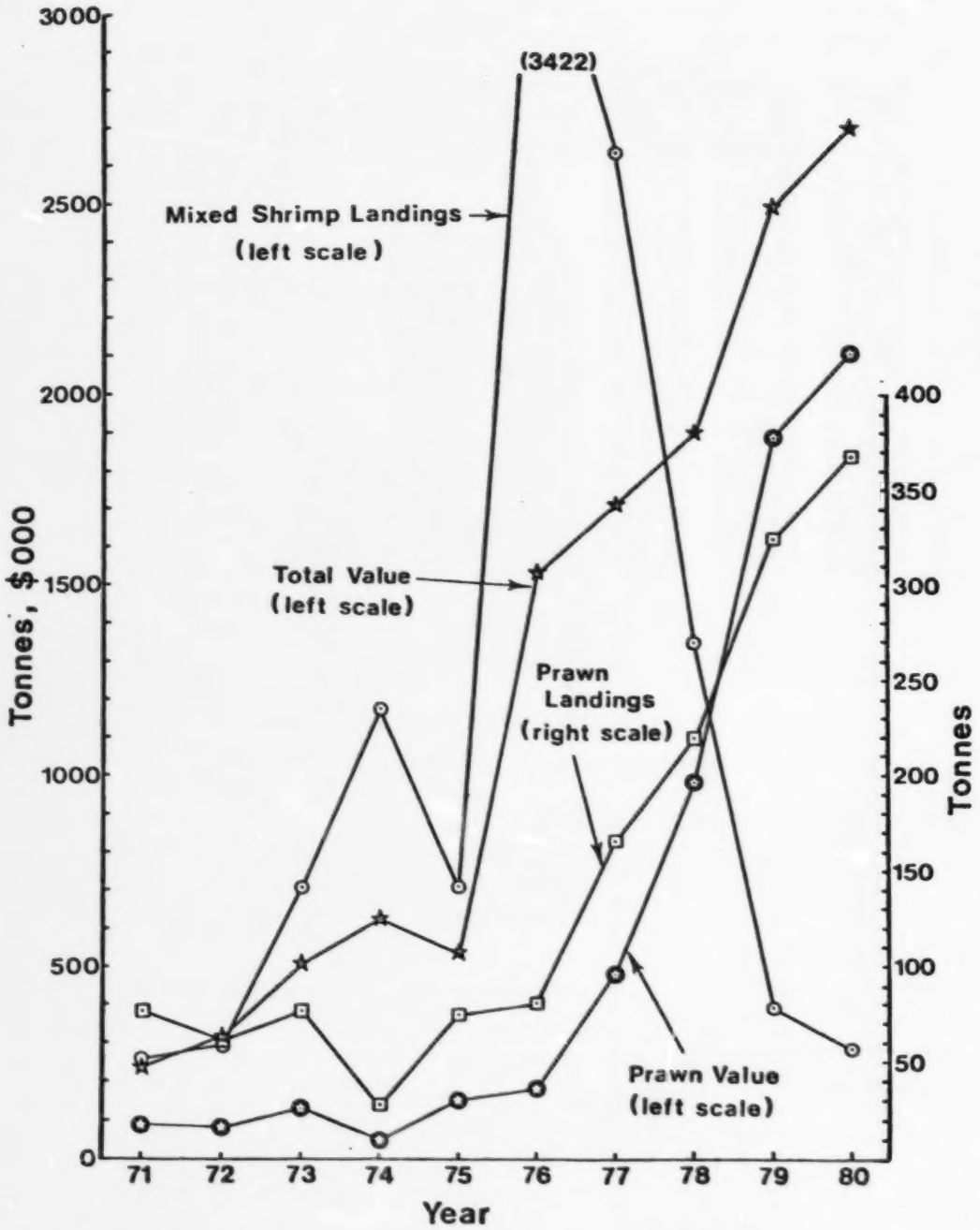


Fig. 5. Prawn landings, mixed shrimp landings, landed values, 1971-1980 (Annual summary of B.C. catch statistics, Fisheries and Oceans Canada, Pacific Region).

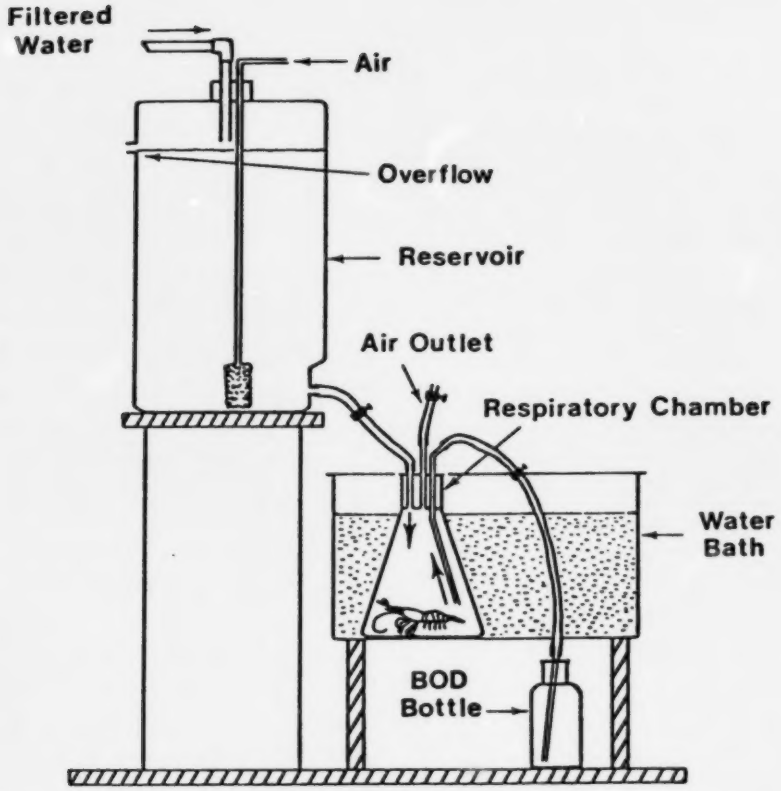


Fig. 6. Static respirometry apparatus - chemical evaluation.

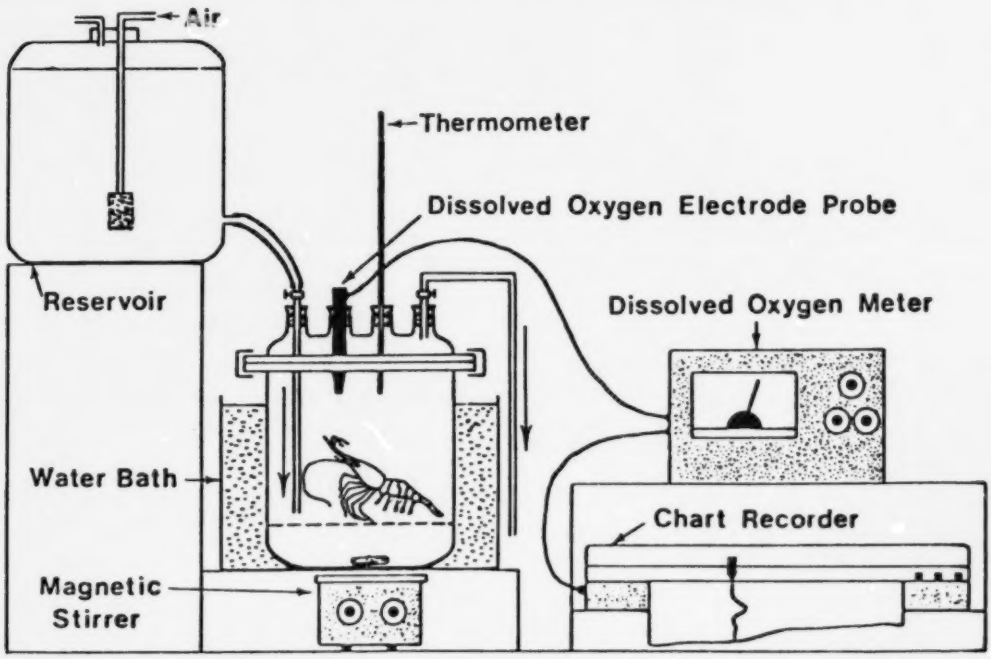


Fig. 7. Static respirometry apparatus - electrode probe evaluation.

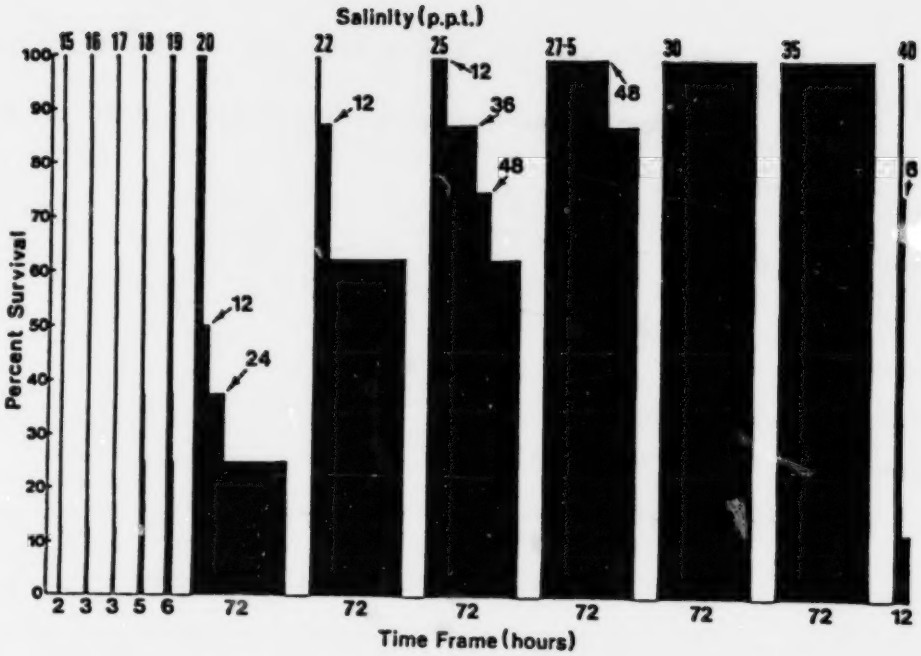


Fig. 8. Tolerance of the prawn, P. platyceros, to salinity changes.

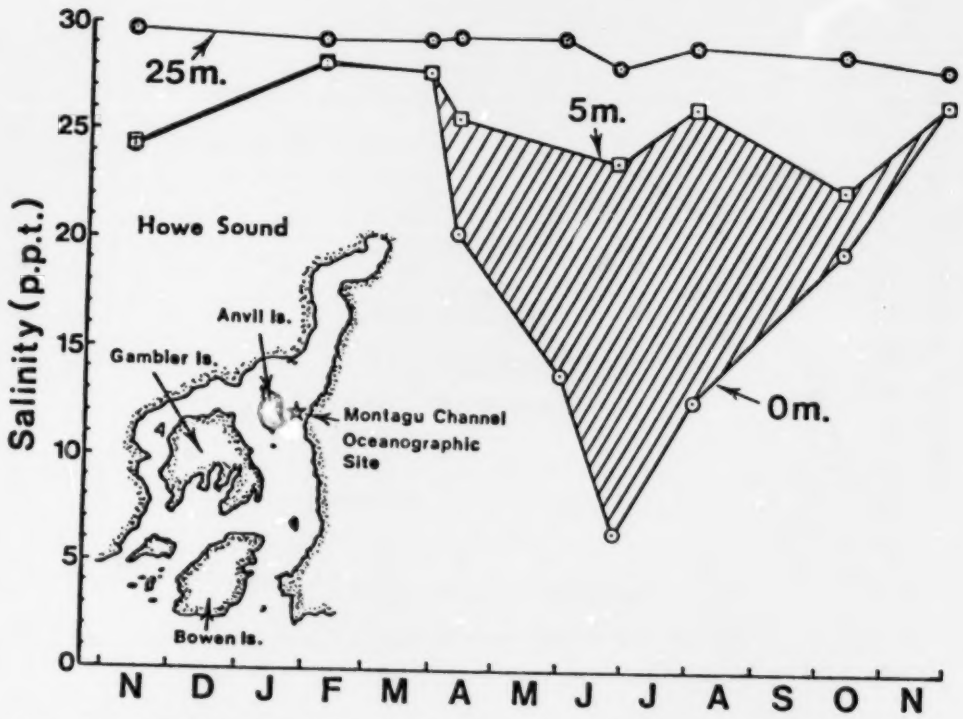


Fig. 9. Seasonal variation in salinity with depth in Howe Sound.

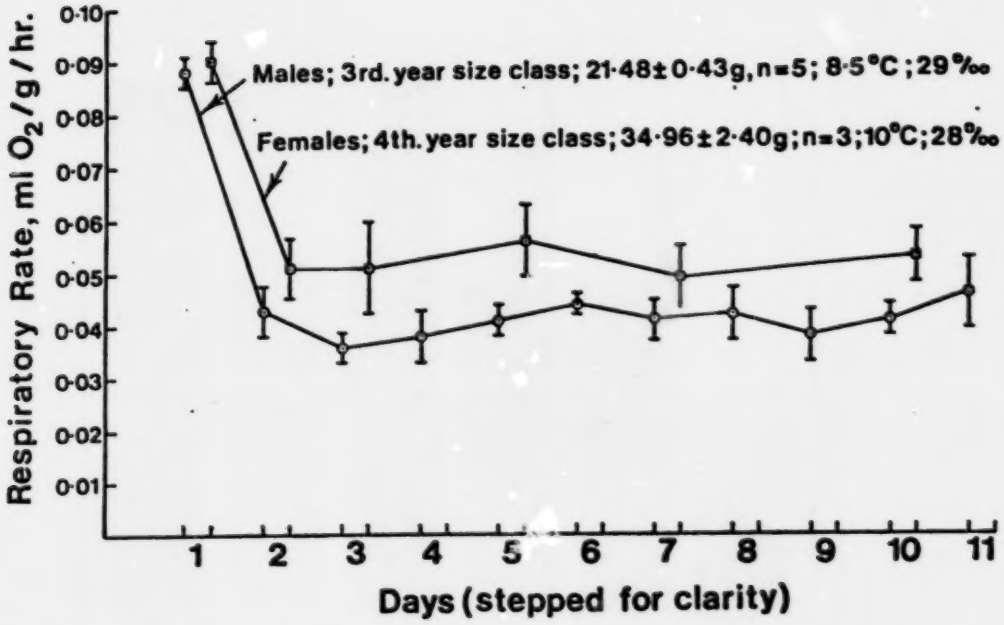


Fig. 10. Oxygen consumption of the prawn, starved for a period of days.

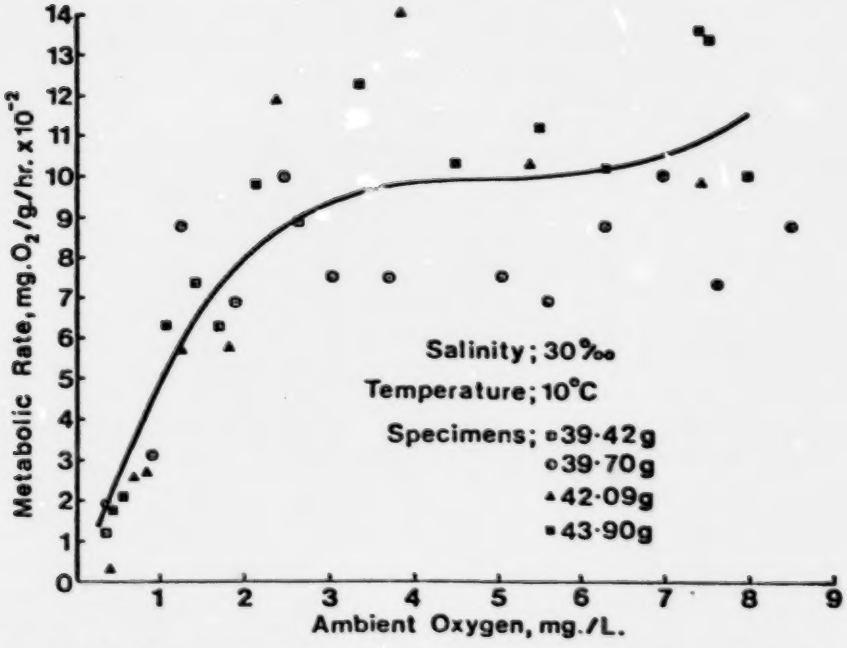

Metabolic Rate, mg. O_2/g/hr. x 10^{-2}
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Salinity; 30‰
Temperature; 10°C
Specimens; ▫39·42g
○39·70g
▲42·09g
▪43·90g
1 2 3 4 5 6 7 8 9
Ambient Oxygen, mg./L.

Fig. 11. Metabolic rate of the prawn versus ambient oxygen levels, at 10°C and 30°/oo salinity.

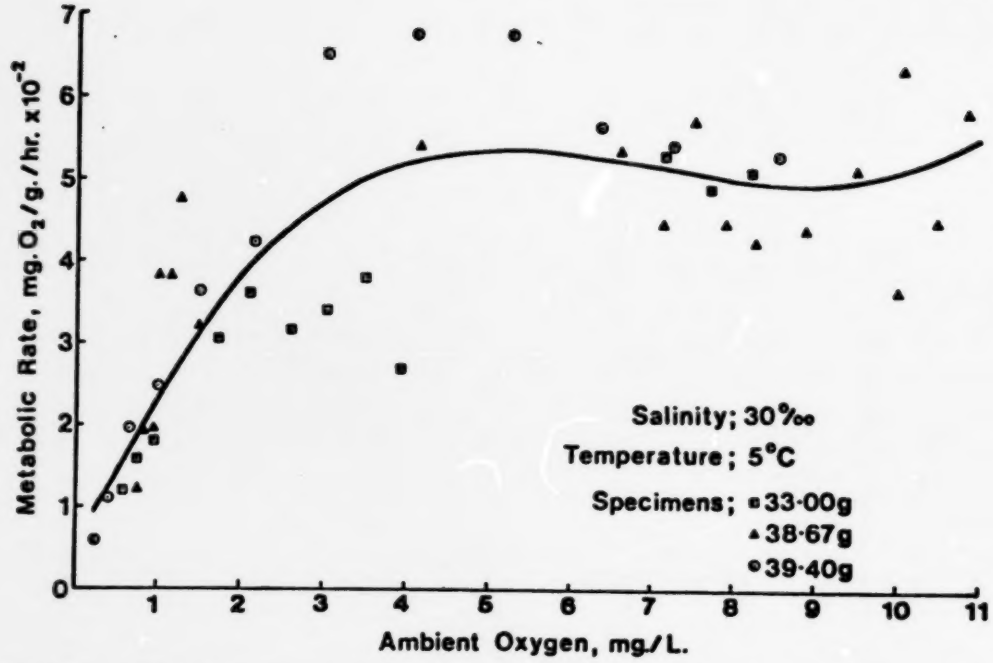


Fig. 12. Metabolic rate of the prawn versus ambient oxygen, at 5°C and 30°/oo salinity.

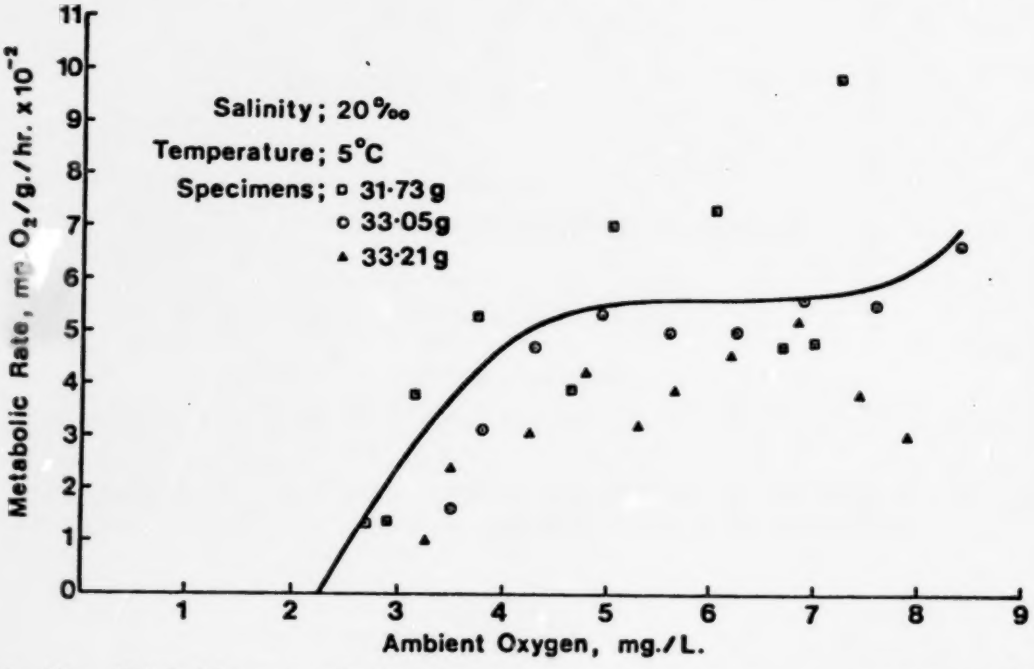


Fig. 13. Metabolic rate of the prawn versus ambient oxygen, at 5°C and 20°/oo salinity.

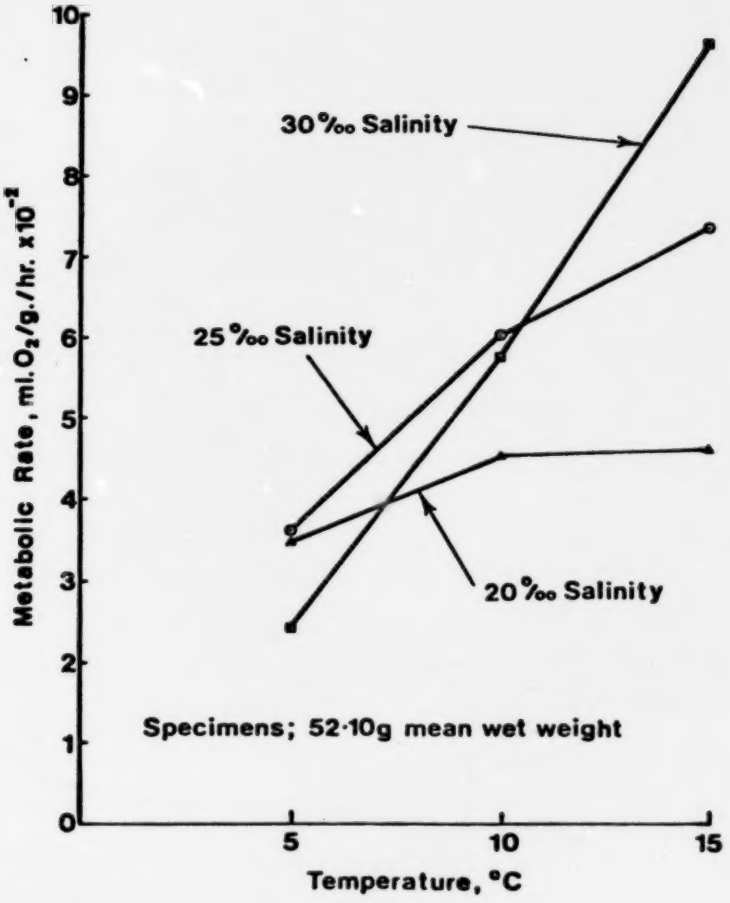


Fig. 14. Changes in the mean metabolic rate of the prawn, P. platyceros, with temperature and salinity.

APPENDIX 1. Data record of effect of population density on size class mortality of P. platyceros.

	Mean cumulative percentage mortality over holding period.											
	4 year class density			3 year class density			2 year class density			1 year class density		
Days	1	2	4	1	2	4	1	2	4	1	2	4
1	0	0	0	0	0	0.7	0	0	0	0	0	0
2	0	0	1.1	0	0	"	0	0	1.5	0	1.5	1.5
3	0	0	"	0	0	1.5	0	1.5	3.0	0	"	3.0
4	0	0	"	0	0	"	0	4.5	3.7	0	6.1	3.7
5	0	0	2.2	0	0	2.2	0	"	5.2	3	"	5.2
6	0	0	"	0	0	3.0	0	"	5.9	"	7.6	5.9
7	0	1.5	4.4	0	0	4.4	6.1	"	7.4	"	9.1	6.7
8	0	"	"	0	1.5	"	9.1	6.1	"	"	12.1	8.1
9	0	"	5.6	0	"	5.9	"	"	8.1	"	"	9.6
10	0	"	"	0	"	"	"	"	"	9	13.6	10.4
11	0	"	6.7	0	"	6.7	"	7.6	8.9	"	18.2	12.6
12	0	"	7.8	0	"	8.1	12.1	9.1	9.6	12	"	14.8
13	0	"	"	0	"	8.9	"	"	"	"	19.7	15.6
14	0	"	"	0	"	"	"	12.1	10.4	"	21.2	17.8
15	0	"	"	0	"	9.6	"	"	11.1	"	22.7	19.3
16	0	"	"	0	"	"	"	"	12.0	"	24.2	20.0
17	0	3.0	"	0	"	"	15.2	16.7	13.3	15.2	27.3	23.0
18	0	"	8.9	3	3.0	11.1	"	"	15.6	"	28.8	24.4
19	0	"	14.4	"	"	"	"	"	"	"	30.3	28.1
20	0	"	"	"	"	"	"	"	17.0	"	33.3	29.6
21	3	4.5	"	"	4.5	15.6	18.2	"	17.8	"	37.9	"
22	"	"	16.7	"	6.1	18.5	"	"	18.5	"	40.9	30.4
23	"	"	20.0	"	"	"	"	19.7	19.3	"	43.9	36.3
24	"	"	22.2	"	"	20.7	"	"	23.0	"	45.5	37.8
25	"	"	"	"	9.1	23.0	"	"	24.4	18.2	47.0	40.0
26	6.1	"	24.4	"	"	23.7	"	21.2	25.9	"	50.0	42.2
27	"	"	25.6	"	"	"	21.2	22.7	"	"	"	43.7
28	"	"	"	"	"	24.4	"	"	26.6	"	"	47.4
29	"	"	"	"	"	25.9	"	"	"	"	54.5	48.1
30	"	"	27.7	"	"	28.9	"	"	"	21.2	"	49.6

Density = individuals per 100 cm^2

APPENDIX 2. Summary table of two-factor analysis of variance on routine metabolic rates of *Pandalus platyceros*

Source of variation	SS	DF	MS
Total	0.022268	44	
Cells	0.019451	8	
Factor A (temperature)	0.011995	2	0.005998
Factor B (salinity)	0.002679	2	0.001340
A X B	0.010135	4	0.002534
Within cells (error)	0.002817	36	0.000079

For H_0: There is no effect of temperature on metabolic rate.

$$F = \frac{\text{temperature MS}}{\text{error MS}} = \frac{0.005998}{0.000079} = 75.92$$

$F_{0.05(1)2,36} = 4.11$ $P<0.005$

Therefore reject H_0

For H_0: There is no effect of salinity on metabolic rate.

$$F = \frac{\text{salinity MS}}{\text{error MS}} = \frac{0.001340}{0.000079} = 16.962$$

$F_{0.05(1)2,36} = 4.11$ $P<0.005$

Therefore reject H_0

SS = Sum of squares

DF = Degrees of freedom

MS = Mean squares

APPENDIX 3. Summary of one-way analysis of variance on routine metabolic rates of Pandalus platyceros

Example: Summary Table

A) Salinity 20°/oo H_0: Metabolic rate at 5°C = M.R. at 10°C = M.R. at 15°C

Source of variation	SS	DF	MS
Total	0.001099	14	
Among	0.004010	2	0.0002005
Within	0.000698	12	0.0000582

$F = 3.468955$ $F_{0.05(1),2,12} = 5.10$ $0.10<P<0.05$

Therefore do not reject H_0

B) Salinity 25°/oo H_0: Metabolic rate at 5°C = M.R. at 10°C = M.R. at 15°C

$F = 20.30$ $F_{0.05(1),2,12} = 5.10$

Therefore reject H_0

C) Salinity 30°/oo H_0: Metabolic rate at 5°C = M.R. at 10°C = M.R. at 15°C

$F = 73.16$ $F_{0.05(1),2,12} = 5.10$

Therefore reject H_0

D) Temperature 5°C H_0: M.R. at 20°/oo = M.R. at 25°/oo = M.R. at 30°/oo

$F = 2.534$ $F_{0.05(1),2,12} = 5.10$

Therefore do not reject H_0

E) Temperature 10°C H_0: M.R. at 20°/oo = M.R. at 25°/oo = M.R. at 30°/oo

$F = 5.21$ $F_{0.05(1),2,12} = 5.10$

Therefore reject H_0

F) Temperature 15°C H_0: M.R. at 20°/oo = M.R. at 25°/oo = M.R. at 30°/oo

$F = 33.85$ $F_{0.05(1),2,12} = 5.10$

Therefore reject H_0

M.R. = Metabolic rate.